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THE X-RAY BACKGROUND FROM GROUPS AND CLUSTERS OF GALAXIES

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ABSTRACT

We present an estimate of the X-ray background (XRB) spectrum from the warm-hot intergalactic medium (IGM) associated with groups and clusters of galaxies, using purely the observationally determined X-ray luminosity function (XLF) and X-ray luminosity ($L_{\rm x}$) - temperature (T) relations for groups and clusters. As compared with previous semi-analytic models based on the Press-Schechter mass function, our approach provides a much simpler and more realistic way to evaluate the XRB from groups and clusters in the sense that we make no assumption about the dynamical and heating properties of the IGM, and the intrinsic dispersion in the $L_{\rm x}$-T relations due to different physical mechanisms among different groups and clusters can be also included. It shows that the resulting 0.1-10 keV XRB spectrum by summing up the X-ray emission from all groups and clusters is consistent with current upper limits placed on the contribution from diffuse gas to the XRB. This may have profound implications for our understanding of the missing baryons in the universe.

Subject headings: cosmology: theory — diffuse radiation — intergalactic medium — X-ray: general

1. INTRODUCTION

The missing baryon problem still has no resolution in sight at present. It is commonly believed that most of the baryons in the universe exist in the form of diffuse warm-hot intergalactic medium (IGM) at temperatures of $T \sim 10^5$–10^7 K (Cen & Ostriker 1999), which may contribute a non-negligible fraction of the soft X-ray background (XRB) as a result of thermal bremsstrahlung emission. Therefore, the measurement of the soft XRB constitutes a critical test for the presence of the warm-hot IGM and also for the models of structure formation. Important progress in the issue has been made over the past few years (e.g. Pen 1999; Phillips, Ostriker & Cen 2000; Wu, Fabian & Nulsen 2001; Davé et al. 2001; Voit, Evrard & Bryan 2001). Essentially, most of the warm-hot IGM associated with the gravitational potentials of less massive dark halos must reside outside of the systems characterized by their virial radii. Otherwise, the XRB produced by the gravitationally heated and bound IGM in groups and poor clusters will greatly exceed the upper limits set by current X-ray observations. This implies that the preheating of IGM either by non-gravitational processes such as supernovae, AGNs and galactic winds or by purely gravitational processes due to large-scale density perturbations must play a potentially important role in the early phase of structure formation, which raises the IGM entropy and makes the IGM harder to compress. Such a scenario is supported by both the discovery of the entropy excess in groups relative to that can be achieved in the pure accretion shock heating (Ponman, Cannon & Navarro 1999) and the remarkable departure of the observed X-ray luminosity ($L_{\rm x}$) - temperature (T) relations for groups and clusters ($L_{\rm x} \propto T^{3-5}$) (Xue & Wu 2000 and references therein) from the simple gravitational scaling law ($L_{\rm x} \propto T^2$) (Kaiser 1986).

While a sophisticated estimate of the XRB produced by the warm-hot IGM must rely upon cosmological hydrodynamic simulations (e.g. Phillips et al. 2000), semi-analytic models, which emphasize the essential physics behind the problem, provide a simple approach to understanding quantitatively the issue, in a complementary manner to hydrodynamic simulations. Indeed, the pioneering work of Pen (1999) based on the cosmic virial theorem and the standard Press-Schechter (PS) mass function has already revealed the properties of the expected XRB from the gravitationally bound IGM within the virialized systems, in gross consistency with subsequent numerical results. In particular, the employment of the observed X-ray luminosity - temperature relations for groups and clusters in the prediction of the XRB spectra permits the inclusion of other heating effects on the IGM, regardless of the details of heating mechanisms and processes (Kitayama, Sasaki & Suto 1998; Wu et al. 2001). In this paper, we conduct an alternative, semi-analytic approach to the estimate of the XRB, using purely the observationally determined quantities such as the X-ray luminosity function (XLF) of groups and clusters and their X-ray luminosity - temperature relations. The advantages of this method are as follows: First, it provides a much simpler and also more realistic way to estimate the contribution of the warm-hot IGM contained in groups and clusters to XRB, in the sense that the influence of non-gravitational heating on the IGM can be naturally included; Second, it allows one to correctly remove the component from known population of groups and especially clusters in the measurement of XRB, which will be of potential importance in search for the missing baryons residing in large-scale structures; Finally, it will be interesting to compare the XRB expected from the XLF and $L_{\rm x}$-T relations of groups and clusters with other independent observational constraints such as the current XRB surveys by *ROSAT*, *ASCA*, *Chandra* and *XMM*. Of course, the accuracy and reliability of this semi-analytic method depend on our knowledge of X-ray groups and clusters revealed by current X-ray observations. We have recently applied the same method to the study of the Sunyaev-Zeldovich cluster counts, and found a noticeable difference between the prediction by the PS mass

function and that by the XLF of clusters (Xue & Wu 2001). Throughout this paper we assume a flat cosmological model (ΛCDM) of $\Omega_{\rm M} = 0.3$, $\Omega_\Lambda = 0.7$ and $h = 0.68$.

2. $L_{\rm X}$-T RELATION

The X-ray luminosity - temperature relation is a good indicator of the dynamical and heating properties of the IGM associated with the underlying gravitational potentials of dark halos. It follows that the bolometric X-ray luminosity of groups and clusters should obey the simple gravitational scaling law $L_{\rm x}^{\rm bol} \propto T^2$, if there is no other heating mechanism (Kaiser 1986). However, it has been well known that the observationally determined $L_{\rm x}^{\rm bol}$-T relations on group and cluster scales deviate significantly from this simple scaling, with $L_{\rm x}^{\rm bol} \propto T^{3-5}$ (e.g. Edge & Stewart 1991; David et al. 1993; Wu, Xue & Fang 1999; Xue & Wu 2000 and references therein). This is often interpreted as being due to the preheating of IGM by supernova explosions and/or AGNs before the IGM falls into the dark matter potential of groups and clusters (e.g. Kaiser 1991; Cavaliere, Menci & Tozzi 1997; Balogh, Babul & Patton 1999; but see Bryan 2000). Consequently, the employment of the observed $L_{\rm x}$-T relations in the estimate of the XRB from the IGM in groups and clusters may allow us to include the non-gravitational heating effect.

We determine the $L_{\rm x}$-T relations for groups and clusters using the non-exhausted catalog of X-ray groups and clusters compiled by Wu et al. (1999) and Xue & Wu (2000). The updated catalog contains 55 groups and 191 clusters whose X-ray temperature and luminosity are both available, and the corresponding $L_{\rm x}$-T relation in the 0.5-2.0 keV band is shown in the upper panel of Figure 1. In order to properly take the intrinsic dispersion of the $L_{\rm x}$-T distribution into account in our estimate of XRB below, we smooth the observed data points in the following way: For any given X-ray luminosity $L_{\rm x}$, we construct a subsample of ten neighbor groups/clusters that have the minimum value of $|L_{\rm x,i} - L_{\rm x}|$. The average temperature of the ten groups/clusters weighted by their measurement uncertainties (ΔT_i) is used as the central temperature T at $L_{\rm x}$: $T = \sum(T_i/\Delta T_i^2)/\sum(1/\Delta T_i^2)$. The temperature scatter around the central temperature T is described by the standard deviation of the ten data points ($T_i, i = 1, \cdots, 10$) from T. The reconstructed $L_{\rm x}$-T relation over a broad X-ray luminosity range of $4.5 \times 10^{40} < L_x < 6.8 \times 10^{44}$ erg s^{-1} in the 0.5-2.0 keV band is displayed in the lower panel of Figure 1. Nevertheless, at the lower and higher X-ray luminosity ends beyond the above range the best fit $L_{\rm x}$-T relations for groups and clusters will be used, which read

$$kT = 10^{0.41\pm0.13} L_{\rm x}^{0.19\pm0.06} \quad \text{groups;} \tag{1}$$

$$kT = 10^{0.73\pm0.05} L_{\rm x}^{0.41\pm0.01} \quad \text{clusters,} \tag{2}$$

where $L_{\rm x}$ and kT are in units of 10^{44} erg s^{-1} (in the 0.5-2.0 keV band) and keV, respectively. The two relations intersect at $L_{\rm x} = 3.5 \times 10^{42}$ erg s^{-1}, and show no apparent evolution at least out to $z \approx 0.8$ (e.g. Mushotzky & Scharf 1997; Della Ceca et al. 2000).

3. XLF

Essentially, we follow an approach similar to our recent application of the XLF of clusters for the expectation of the Sunyaev-Zeldovich cluster counts (Xue & Wu 2001). We model the differential XLF of groups/clusters by the Schechter function (e.g. Ebeling et al. 1997; Collins et al. 1997; Rosati et al. 1998; 2000; Burke et al. 1997; De Grandi et al. 1999):

$$\frac{dn}{dL_{\rm x}} = A \exp(L_{\rm x}/L_{\rm x}^*) L_{\rm x}^{-\alpha}, \tag{3}$$

We consider both the non-evolving and evolving XLFs of groups and clusters, which can be characterized by $A = A_0(1+z)^{\bar{A}}$ and $L_{\rm x}^* = L_{\rm x0}^*(1+z)^{\bar{B}}$. For the non-evolving XLF ($\bar{A} = 0$ and $\bar{B} = 0$), we adopt the local XLF constructed by Ebeling et al. (1997) in the 0.5-2 keV band: $A_0 = 3.32^{+0.33}_{-0.36} \times 10^{-7}$ Mpc^{-3} (10^{44} ergs s^{-1})$^{\alpha-1}$, $L_{\rm x0}^* = 5.70^{+1.29}_{-0.93} \times 10^{44}$ ergs s^{-1} and $\alpha = 1.85^{+0.09}_{-0.09}$, where the Hubble constant is $h = 0.5$. For the evolving XLF, we use the evolution parameters given by Rosati et al. (2000) for an Einstein-de-Sitter universe: $\bar{A} \approx 0$ and $\bar{B} = -3$. We also adopt a combined model or partially evolving XLF suggested recently by Gioia et al. (2001), in which the non-evolving XLF given by Ebeling et al. (1997) is applied to all groups and clusters except for the luminous clusters beyond $z = 0.3$ and with $L_{\rm x} \geq 1.8 \times 10^{44}$ erg s^{-1} in the 0.5-2 keV band. For the latter we choose $\bar{A} \approx 0$ and $\bar{B} = -3$. We convert the above XLFs and X-ray luminosity $L_{\rm x,0}$ in the Einstein-de-Sitter universe into the ones in the ΛCDM model by demanding that the observed number of groups/clusters in a given redshift interval $(z, z+dz)$ be conserved and by utilizing the relation

$$L_{\rm x} = \left[\frac{D_L}{D_{L,0}}\right]^2 L_{\rm x,0}, \tag{4}$$

where D_L and $D_{L,0}$ are the corresponding luminosity distances. Note that the current XLFs are only valid down to $L_{\rm x} \approx 1 \times 10^{42}$ erg s^{-1} in the 0.5-2 keV band. Nevertheless, in order to test how significant the X-ray emission from the warm gas associated with elliptical galaxies and small groups affects the soft XRB, we will make an attempt to extrapolate the current XLFs to $L_{\rm x,min} = 1 \times 10^{40}$ erg s^{-1}.

4. XRB: EXPECTATION

Integrating the X-ray emission of all the groups and clusters with X-ray luminosity above the threshold $L_{\rm x,min}$ and over redshift space yields the total XRB intensity at a given frequency ν:

$$J(\nu) = \int\int \left(\frac{dL_{\rm x}/d\nu}{4\pi D_{\rm L}^2(z)}\right)\left(\frac{dn(L_{\rm x},z)}{dL_{\rm x}}\right)\left(\frac{dV}{d\Omega dz}\right) dL_{\rm x} dz, \tag{5}$$

where dV is the comoving volume element:

$$\frac{dV}{d\Omega} = \frac{c}{H_0}\frac{(1+z)^2}{E(z)} D_{\rm A}^2 dz, \tag{6}$$

$D_{\rm L}(z)$ and $D_{\rm A}(z)$ are the luminosity and angular diameter distances to groups/clusters at z, respectively. Since the $L_{\rm x}$-T relation and XLFs of groups/clusters are both given in the 0.5-2 keV band, we adopt the optically thin and isothermal plasma emission model with a metallicity of $Z = 0.3Z_\odot$ by Raymond & Smith (1977) to convert

the X-ray luminosity in the 0.5-2 keV band into the X-ray luminosity per unit frequency, $dL_{\rm x}/d\nu$, in which line emission is also included.

We numerically integrate equation (5) for the three different evolutionary scenarios of XLF. It turns out that the difference in the expected XRB between the non-evolving and evolving XLFs of groups/clusters is only minor especially when the scatter of the observationally determined $L_{\rm x}$-T relations is included (see Figure 3). Essentially, the non-evolving XLF only leads to a slightly larger XRB flux than the evolving or partially evolving models. Note that the current evolutionary models only admit the pure luminosity evolution of clusters. In Figure 2 we display the resulting 0.1-10 keV XRB spectra for the partially evolving XLF, in which the total XRB is also decomposed into the contributions of groups and clusters separated at $L_{\rm x} = 3.5 \times 10^{42}$ erg s^{-1} in the 0.5-2 keV band and at different redshift ranges. It is apparent that the predicted hard XRB above ~ 1 keV is dominated by clusters at intermediate reshifts $0.1 < z < 1$, while most of the soft XRB is produced by groups, as was naturally expected. In particular, nearby groups within $z = 0.1$ make little contribution to the soft XRB, in contrast to the distant groups beyond $z = 1$ which can give arise to a large fraction of the soft XRB below ~ 0.4 keV.

5. XRB: OBSERVATIONAL CONSTRAINTS

We now compare our predicted XRB flux from the IGM in groups and clusters with the upper limits set by current observations.

A considerably large fraction of the hard (2-10 keV) XRB has been resolved into discrete sources, which contribute a total sky brightness of $(1.3 - 1.75) \times 10^{-11}$ erg s^{-1} cm $^{-2}$ deg^{-2} for flux down to $1.4 - 2 \times 10^{-15}$ erg s^{-1} cm^{-2} (Mushotzky et al. 2000; Giacconi et al. 2001; Hasinger et al. 2001). The new result from 300 ks exposure of the *Chandra* Deep Field South gives a value of $(1.46 \pm 0.20) \times 10^{-11}$ erg s^{-1} cm^{-2} deg^{-2} (Tozzi et al. 2001). Combined with the 2-10 keV background of $1.6{-}2.3 \times 10^{-11}$ erg s^{-1} cm^{-2} deg^{-2} (Gendreau et al. 1995; Marshall et al. 1980; Vecchi et al. 1999), the maximum admitted range of the unresolved flux is $(0 - 1.0) \times 10^{-11}$ erg s^{-1} cm^{-2} deg^{-2}.

In the soft (1-2 keV) band, the total contribution of the resolved sources for flux greater than 2×10^{-16} erg s^{-1} cm^{-2} amounts to $3.38 - 3.55 \times 10^{-12}$ erg s^{-1} cm $^{-2}$ deg^{-2} (M$^{\rm c}$Hardy et al. 1998; Hasinger et al. 1998; Mushotzky et al. 2000; Giacconi et al. 2001; Tozzi et al. 2001). The percentage contribution from the discrete and other sources to the soft XRB depends upon the uncertainty on the evaluation of the total soft XRB which varies from the lowest value 3.7×10^{-12} erg s^{-1} cm $^{-2}$ deg^{-2} (Gendreau et al. 1995), the mid-range value 4.2×10^{-12} erg s^{-1} cm $^{-2}$ deg^{-2} (Miyaji et al. 1998), to the largest value 4.4×10^{-12} erg s^{-1} cm $^{-2}$ deg^{-2} (Chen, Fabian & Gendreau 1997). We adopt two additional upper limits to the soft XRB from diffuse IGM given by Bryan & Voit (2001): 1.8×10^{-12} erg s^{-1} cm $^{-2}$ deg^{-2} and 6.8×10^{-13} erg s^{-1} cm $^{-2}$ deg^{-2} for the 0.5-2 keV and 0.1-0.4 keV bands, respectively. These values are derived by combining the XRB intensity measurements (Gendreau et al. 1995; Barcons, Mateos & Ceballos 2000) and the deep surveys with *ROSAT* and *Chandra* (Hasinger et al. 1998; Giacconi et al. 2001), along with a proper modeling of the spectral slope. Finally, the "remaining" fluxes recently discovered by Kuntz, Snowden & Mushotzky (2001) from the *ROSAT* All-Sky Survey after peeling off various known X-ray foreground and background components can also be used as useful constraints on the XRB from the IGM in groups and clusters, although these remainders may be contaminated by the Galactic halo emission. It should be pointed out that the faint, diffuse X-ray emission from groups and small clusters may also be included in the current resolved 1-2 keV XRB. This arises from the difficulty of clearly separating X-ray emission between nuclear and extended sources at very faint flux level. Moreover, X-ray emission from normal galaxies has become detectable in the recent deep exposure by *Chandra* and *XMM* (Mushotzky et al. 2000; Giacconi et al. 2001; Hasinger et al. 2001; Tozzi et al. 2001). Therefore, the current residual soft XRB after the resolved sources are removed may not strictly be used as an upper limit on the X-ray emission from diffuse IGM associated with elliptical galaxies, groups and clusters.

We first perform an integration of the total XRB in terms of equation (5) over four different energy bands, using again the partially evolving XLF, and compare our predictions with the existing limits (Table 1). Note that in the 0.5-2 keV band, we can obtain the total XRB flux simply by integrating equation (5) without the employment of the $L_{\rm x}$-T relations. Essentially, our predicted results in all the four bands are well within the upper limits placed on the contribution from diffuse gas to the XRB. We then compare our expected XRB spectrum from the IGM in groups and clusters with the observational constraints (Figure 3). For the latter, we use the mean strength of the upper limits over different energy bands except for the data of Kuntz et al. (2001). In order to demonstrate how the scatter in the $L_{\rm x}$-T distribution (see Figure 1) affects our predictions, we employ the Monte Carlo technique to determine the uncertainty (68% confidence limits) in the resulting XRB. It appears that the overall XRB produced by the IGM associated with groups and clusters is roughly consistent with the current upper limits. Namely, the X-ray emission from groups and clusters may account for the remaining XRB flux reported by the advanced X-ray detectors (*ROSAT*, *ASCA*, *Chandra*) after the discrete sources are removed. Note that the upper limits given by Kuntz et al. (2001) at ~ 0.2 keV significantly exceed our predictions, which can be attributable to the contribution from the Galactic halo emission.

We have also compared our predictions with the simulated XRB by Phillips et al. (2000) (Figure 3). For the latter, the contributions from nearby, massive clusters ($z \leq 0.2$ and $M \geq 5.5 \times 10^{14} h^{-1} M_{\odot}$) were removed. This last restriction will not significantly alter our predictions because the effect of the nearby, massive clusters on the total XRB is rather small. It appears that there is good agreement between our analytical results, based on the XLF and $L_{\rm x}$-T relations of groups and clusters, and their numerical simulations over the entire energy band.

6. DISCUSSION AND CONCLUSIONS

We have provided an alternative, semi-analytic model to the estimate of the contribution from the warm-hot IGM associated with groups and clusters to the XRB, based purely on the observationally determined $L_{\rm x}$-T relations

Table 1
XRB: predictions vs observational limits.

Energy range	Upper limit[a]	Prediction[a]
2 - 10 keV	0 - 21	1.1 - 1.9
1 - 2 keV	0.31 - 2.1	0.8 - 1.1
0.5 - 2 keV	3.7	2.4
0.1 - 0.4 keV	1.4	1.4 - 5.2

[a] In units of keV s^{-1} cm^{-2} sr^{-1}

and XLF of groups and clusters. This has enabled us to naturally include both gravitational and non-gravitational heating influence without detailed knowledge of the heating processes. The resulting 0.1-10 keV XRB spectrum is roughly consistent with the upper limits set by current X-ray observations on the contribution from diffuse gas to the XRB (e.g. Hasinger et al. 1998; 2001; Mushotzky et al. 2000; Giacconi et al. 2001; Tozzi et al. 2001). It is thus possible that the residual flux, after the discrete sources are removed from the total XRB, is (at least partially) due to the X-ray emission from the warm-hot IGM associated with groups and clusters. If confirmed, this would have profound implications for our understanding of the missing baryons and their distributions.

As compared with previous semi-analytic models which essentially employ the PS mass function and the mass - temperature relation in terms of virial theorem, combined with either an oversimplified scenario for the IGM distribution in dark halos (e.g. Pen 1999) or the L_x-T relation for clusters (Kitayama et al. 1998; Wu et al. 2001), our semi-analytic approach provides a more straightforward and realistic way to calculate the XRB from the warm-hot IGM associated with groups and clusters. Indeed, we have made no assumption about the dynamical and heating properties of the IGM, and included the intrinsic dispersion, if any, in the L_x-T relations due to different physical mechanisms among different groups and clusters. The uncertainty in our predictions, aside from the dispersion of the L_x-T distribution, thus arises mainly from the XLF of groups and clusters: Firstly, we have extrapolated the current XLF and its evolutionary model to $z > 1$ where the XLF evolution of clusters is poorly constrained. Our main prediction would remain unchanged only if the evolutionary scenario shown by current observations (e.g. Rosati et al. 2000; Gioia et al. 2001; references therein) is correct, i.e., the bulk of clusters exhibit no significant evolution out to $z \sim 1$ and the evolution only commences for the most luminous clusters, and if such a scenario should also be applicable to groups. On the other hand, we have shown that the major uncertainty in the predicted XRB arises from the scatter of the L_x-T relation rather than from the current available evolutionary models of XLF. At this point, it is unlikely that the XBR can be used for the purpose of testing the evolution of XLF for groups and clusters. Second, we have extrapolated the current XLF to less massive systems with X-ray luminosity down to $L_x \approx 1 \times 10^{40}$ erg s^{-1} in the 0.5-2 keV band. This limit even allows us to include the contribution from the X-ray emission of elliptical galaxies, which would affect the estimate of the 0.1-1 keV XRB. Unfortunately, there has been no observational justification for such an extrapolation, except for the consistency between our prediction and the numerical result by Phillips et al. (2000). Third, we have adopted a less vigorous approach to converting the XLF in an Einstein-de-Sitter universe to that in ΛCDM model. A sophisticated treatment of the problem is to reconstruct the XLF of groups and clusters and its evolutionary model in the ΛCDM model from real data, and then proceed to the computation of the XRB from the IGM in groups and clusters, as we have done for the L_x-T relation.

Overall, the XRB spectrum in the 0.1-10 keV band estimated from the available L_x-T relation and XLF of groups and clusters is consistent with the residual XRB reported by current observations after the source contributions are removed. This would be of great significance for future detection of the missing baryons which are believed to exist in the form of the warm-hot IGM associated with poor clusters and groups that are further embedded in large-scale structures.

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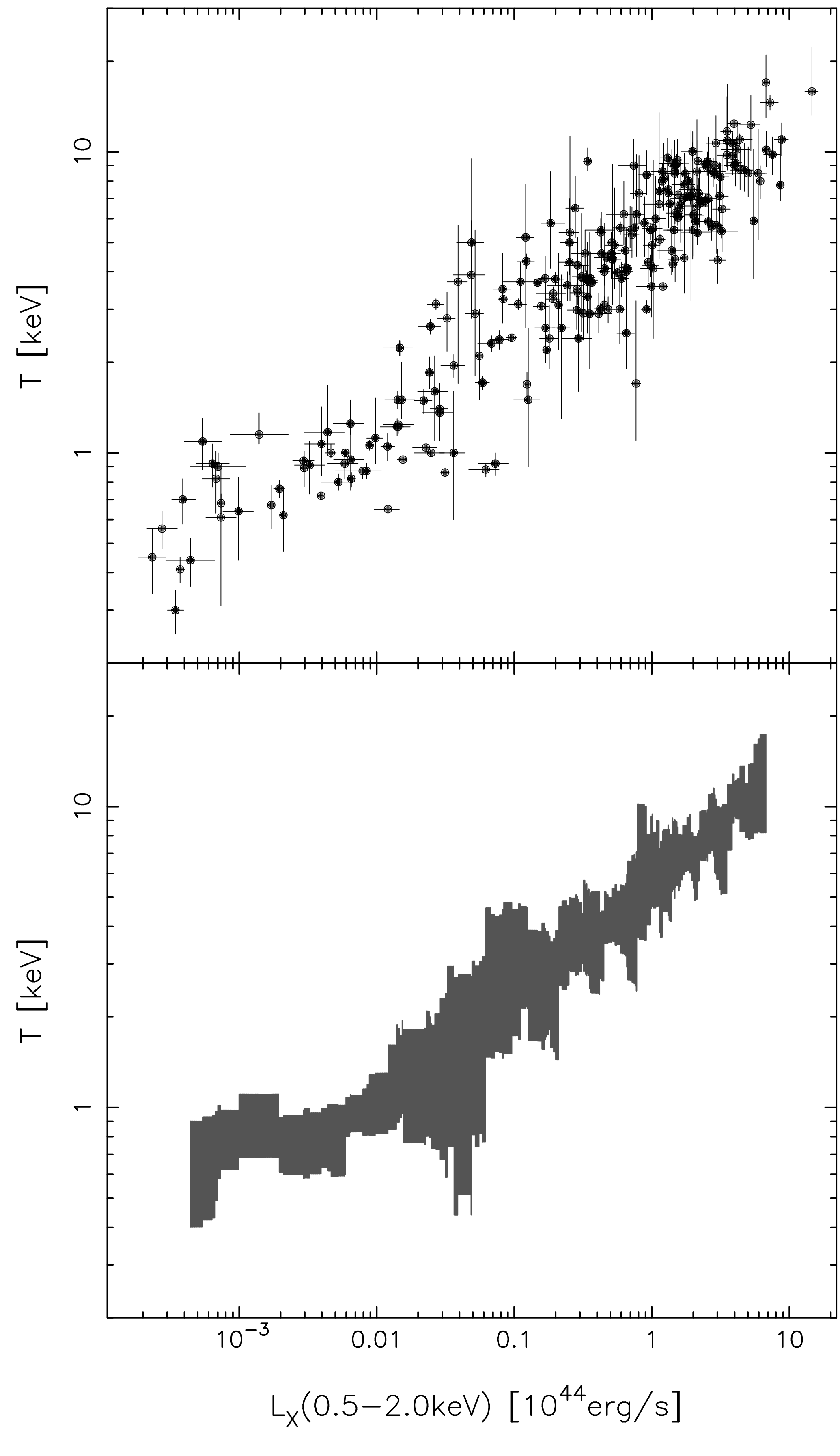
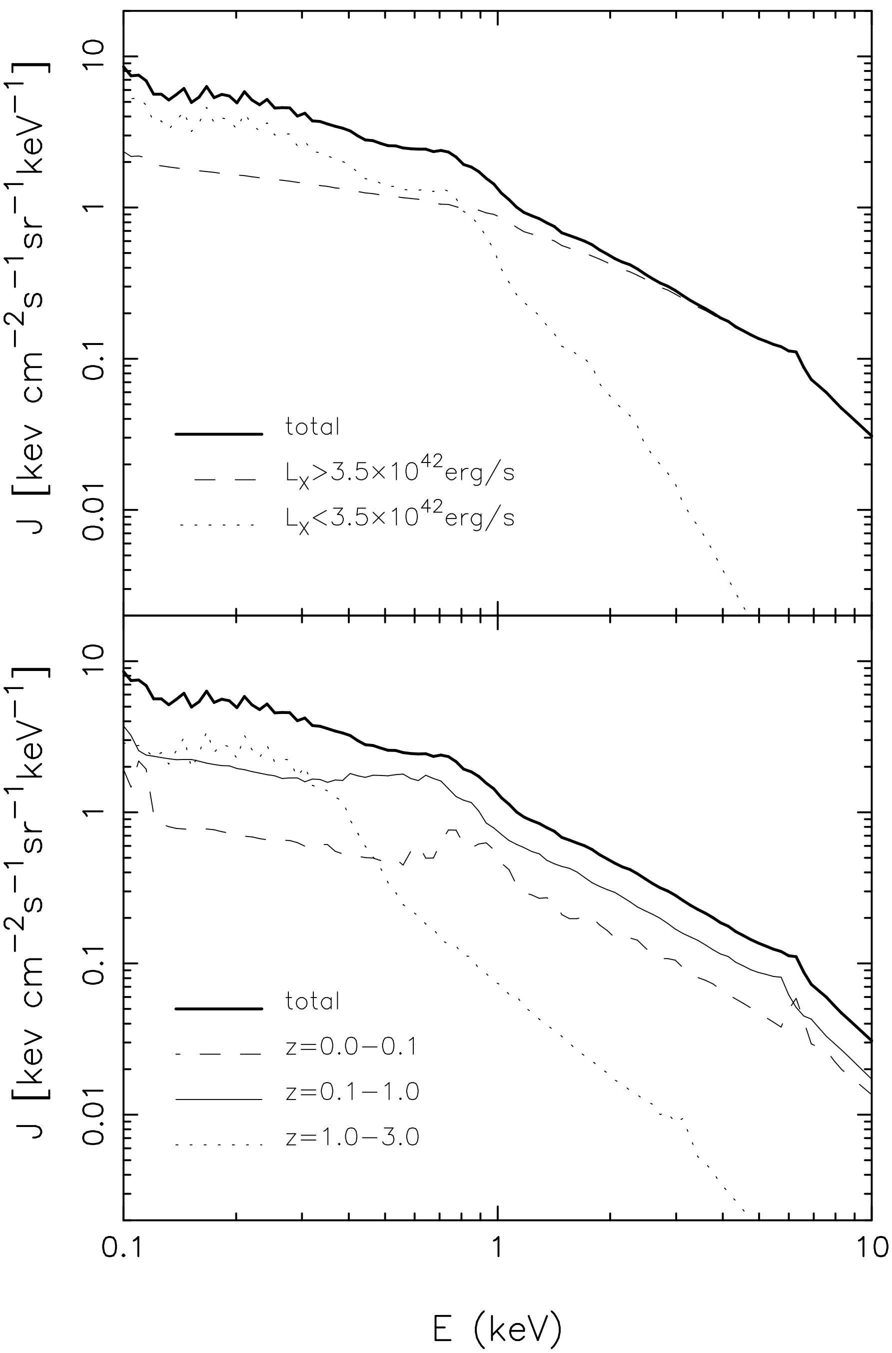
FIG. 1.— X-ray luminosity ($L_{\rm x}$) - temperature (T) relation (ΛCDM model) in the 0.5-2 keV band for groups and clusters. Upper panel: Raw data (55 groups and 191 clusters); Lower panel: Smoothed $L_{\rm x}$-T relation.

FIG. 2.— The XRB spectra predicted by the XLF and L_x-T relations of groups and clusters. The energy resolution is taken to be $\Delta \log E = 0.02$. Upper panel: Contributions of groups (1×10^{40} erg s^{-1} $\leq L_x \leq 3.5 \times 10^{42}$ erg s^{-1}) and clusters ($L_x \geq 3.5 \times 10^{42}$ erg s^{-1}); Lower panel: Contributions of groups and clusters at different redshift ranges.

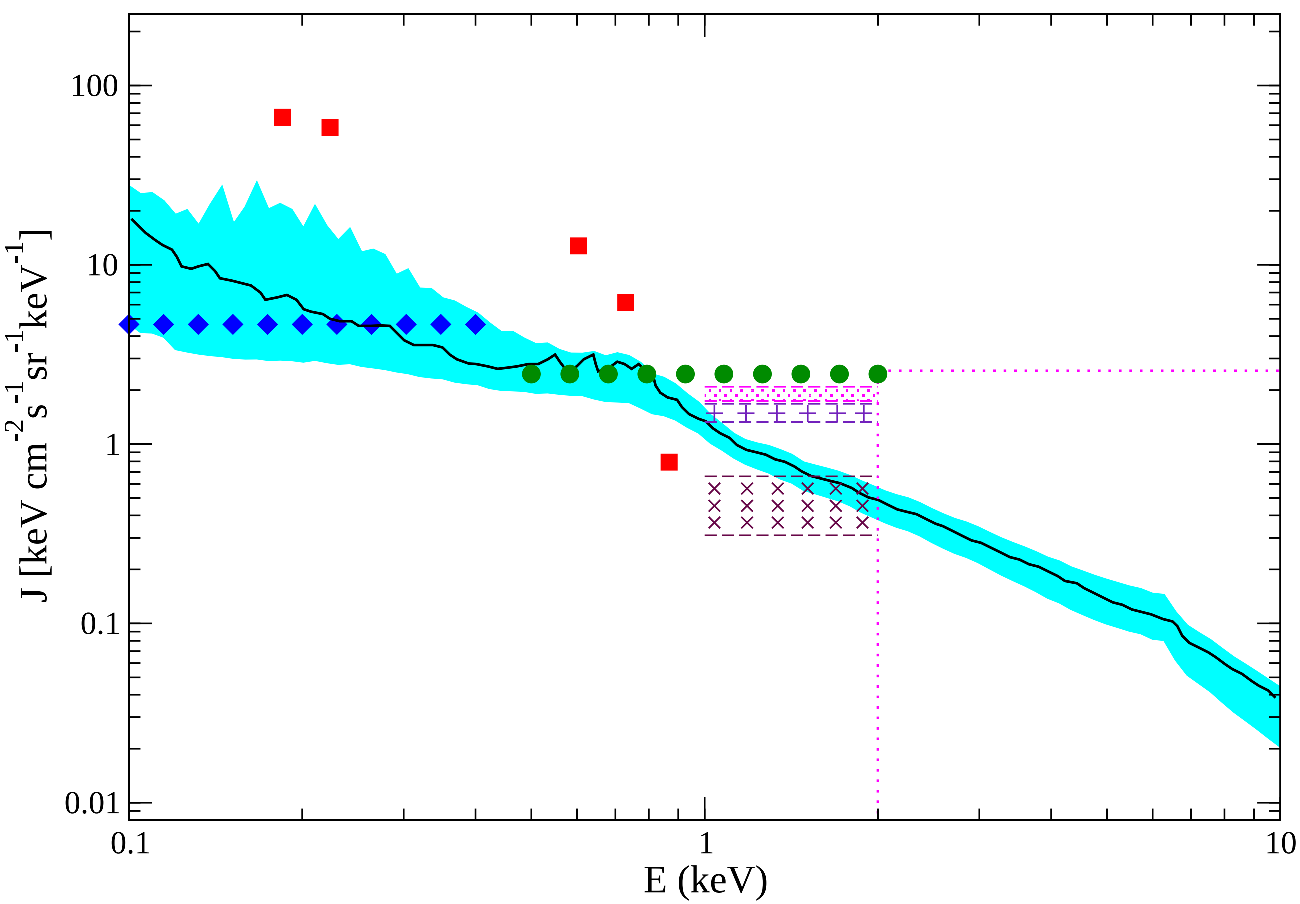
FIG. 3.— Comparison of the predicted XRB by groups and clusters (shadowed region) with the observational constraints on the contribution of diffuse gas to the XRB. Dotted line: the upper limit in the 2-10 keV band (Mushotzky et al. 2000; Giacconi et al. 2001; Tozzi et al. 2001). Three regions filled with different symbols ($\cdot$, $+$, $\times$) in the 1-2 keV range correspond to three evaluations of the total XRB intensity by Chen et al. (1997), Miyaji et al. (1998) and Gendreau (1997), respectively, after the source contributions detected by Hasinger et al. (1998), Mushotzky et al. (2000), Giacconi et al. (2001) & Tozzi et al. (2001) are removed. Filled circles and diamonds are the upper limits derived by Bryan & Voit (2001) in the 0.5-2 and 0.1-0.4 keV bands, respectively. Filled squares are the remaining fluxes detected by Kuntz et al. (2001) after the known X-ray foreground and background components are removed but the Galactic halo emission may be included. The numerically simulated XRB spectrum from the warm-hot IGM by Phillip et al. (2000) is also illustrated by solid line.



T [keV]
10
1
T [keV]
10
1
10^{-3}
0.01
0.1
1
10
L_X(0.5−2.0keV) [10^{44}erg/s]



10
1
0.1
0.01
J [kev cm^{-2}s^{-1}sr^{-1}keV^{-1}]
total
$L_X > 3.5\times10^{42}$erg/s
$L_X < 3.5\times10^{42}$erg/s
10
1
0.1
0.01
J [kev cm^{-2}s^{-1}sr^{-1}keV^{-1}]
total
z=0.0−0.1
z=0.1−1.0
z=1.0−3.0
0.1
1
10
E (keV)



J [keV cm^{-2} s^{-1} sr^{-1} keV^{-1}]
100
10
1
0.1
0.01
0.1
1
10
E (keV)